What are CCQE interactions?

How to measure two body current contribution?

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Outline

- Short reminder of the previous seminar.
- Role of FSI effects.
- Two ideas to see the MEC events:
  - two proton ejection,
  - integrated charged hadrons kinetic energy.
- Comparison of NuWro and GENIE predictions.
- Outlook.

Two weeks ago, resume':

- Only in the case of a free target reaction there is a clear definition of CCQE:

$$\nu_l + n \to l^- + p,$$

$$\bar{\nu}_l + p \to l^+ + n.$$

- In the case of nuclear target there is always a contribution to CC from the two body current.
- A typical experimental signal is: muon and two nucleons in the final state (below or above a threshold).
- We want to know the value of the axial mass (M_A) which characterizes the **free** CCQE reaction, and not M_A^{eff} which can depend on the target, neutrino flux and selection of events.

Two examples how do experimentalists define CCQE

MiniBooNE

- only 2 subevents (Cherenkov light from muon and then from electron)
- no assumptions about proton
- most of CC events with pions give rise to 3 subevents

NOMAD

- 1- and 2-track events (muons and protons with $p > 300$ MeV/c)
- several cuts are imposed to eliminate the (pion) background

How it will be done in the MINERvA?....

Terminology

Meson exchange current (MEC)

$\Updownarrow$

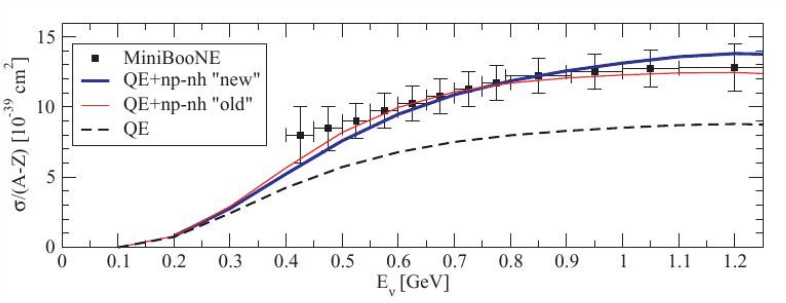
two body current

$\Updownarrow$

n particles n holes ($np - nh$)

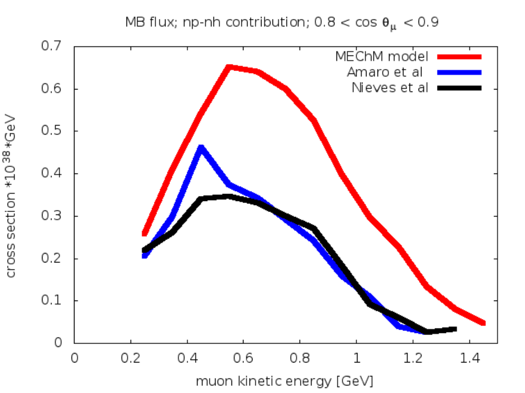
However, sometimes *MEC* refer to a smaller subset of the *two body current* diagrams which lead to *np-nh* final states!

We are speaking about a big effect



QE refer to one nucleon knock out with nuclear effects (RPA) but **before** FSI.

Uncertainty in theoretical computations



Remember that there is no correlation contribution in the Amaro et al computations!

How to measure the MEC contribution?

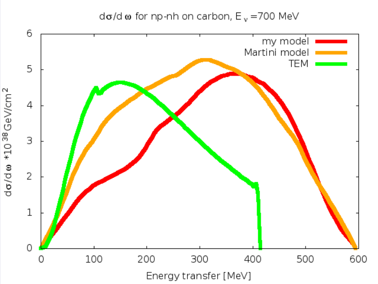
- of interest are CCQE-like events, with no pions in the final statements; one needs a strong veto on pions
- one must use the information contained in reconstructed proton tracks and in the *vertex activity*
- it is better to have a low threshold for reconstruction proton tracks
- the quality of FSI model is very important, pion absorption seems to be the most important background
- observables like integrated kinetic energy are less affected by FSI.

Some predictions – upgrade

- During last two weeks I developed a new model (previously called and implemented it in MC (NuWro). Unfortunately, for $E_\nu > 2$ GeV the code is very slow.
- All the distributions are shown for $E_\nu = 2$ GeV, carbon target
- There will be also a comparison with GENIE at 1 GeV, carbon target
- An important ingredient of the cascade model is *formation zone*, the minimal distance from the interaction point where possible reinteractions can happen
- I compare three situations
  - no reinteractions
  - reinteractions, no FZ
  - reinteraction, with FZ

All the predictions I am showing you are still PRELIMINARY.

A model used in my calculations

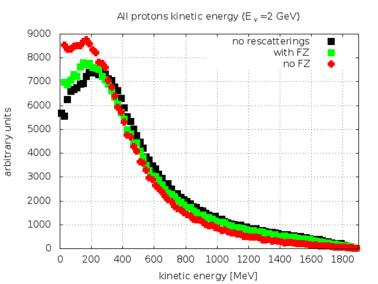


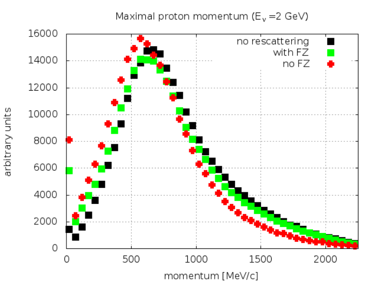
It is intended to be similar to the Marteau-Martini model.

The MEC effect is much larger than for TEM. Two reasons: larger np-nh cross section and larger typical energy transfers.

Some predictions (1)

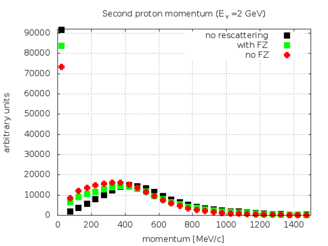
The idea is to estimate an impact of nucleon rescatterings

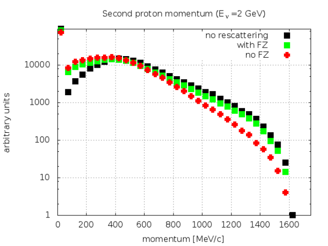


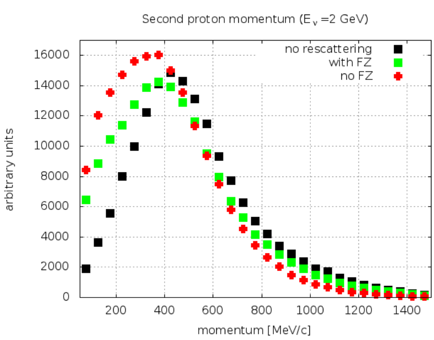


We see that due to rescatterings some energy is dissipated

Some predictions –2







If the second proton is energetic enough we can see a pair of protons in one event.

IDEA 1: Pairs of reconstructed protons

1 GeV. Only CC. Carbon target. The format of each entry is SIGNAL+BACKGROUND. Normalized to 100 kiloevents. GENIE simulations done by Steve Dytman – THANK YOU!

pion ↓	proton →	300 $\frac{MeV}{c}$	400 $\frac{MeV}{c}$	500 $\frac{MeV}{c}$
0	GENIE	2908+4204	1999+2447	1262+1170
	NuWro	6805+4527	4957+3501	3036+1656
100 $\frac{MeV}{c}$	GENIE	2908+4337	1999+2485	1262+1177
	NuWro	6837+4687	4975+3574	3045+1675
200 $\frac{MeV}{c}$	GENIE	2908+4707	1999+2651	1262+1233
	NuWro	6866+5901	4993+4111	3049+1832

For the BCKG an agreement within 50%, much better for 300 MeV/c cut. For the signal difference by a factor of 2.5. Even for GENIE the signal is bigger than BCKG error.

We speak about a very big effect!

IDEA 2: Integrated hadronic kinetic energy

Define two observables: $\sum_j T_j$ and $\frac{\sum_j T_j}{E_\mu}$, where T_j is the kinetic energy of charged hadron. We include all the kinetic energy: both reconstructed hadrons and blobs.

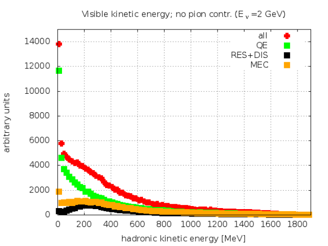
Assume we eliminate all π^0.

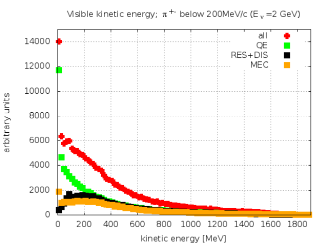
Two assumptions about $\pi^\pm$:

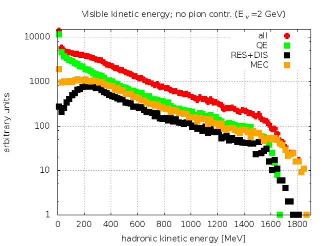
(a) we eliminate (not include) all of them

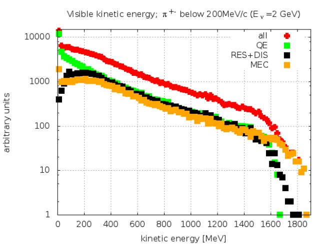
(b) we can eliminate (not include) them if their momenta are larger than 200 MeV/c.

IDEA 2: Integrated hadronic kinetic energy









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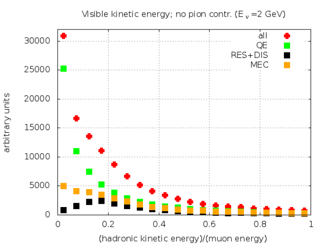

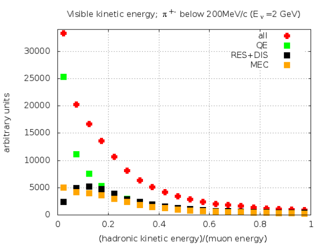

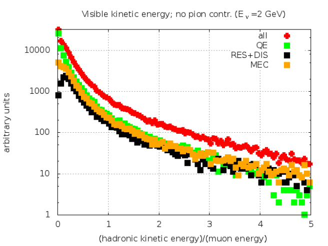

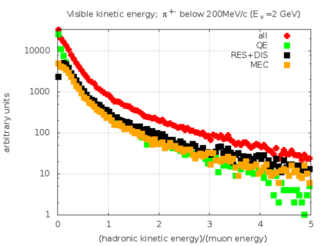

Conclusions

- There are large theoretical uncertainties.
- The MEC contribution seems to be really large.
- Hopefully, there is a chance to see the effect or at least to put some constraints on the models?